# Assessment of UAV Operators by Human Factor Analysis and Classification System (HFACS) Based on AHP

**Omar Alharasees and Utku Kale**

## Nomenclature

| | |
|---|---|
| AHP | Analytic hierarchy process |
| HFACS | Human factor analysis and classification system |
| UAV | Unmanned aeronautical vehicle |
| DOD | Department of Defense |
| UAS | Unmanned aircraft system |

## 1 Introduction

Researchers' assessments aim to justify and understand the main reasons leading to failures in UAV operations, illustrate the leading cause, and improve system safety by presenting recommendations that can be used in the industry to reach a sustainable system. Even in unmanned aircraft systems (UAS) incidents and accidents, human error has been established as a primary component of many major aviation catastrophes. Human error frameworks such as HFACS and "Reason's Swiss cheese model" have been used to identify and evaluate contributing variables of accidents linked to human error in order to avoid future mishaps.

HFACS is one of the most extensively utilized technical models in the field to assess human factors among various accident analysis models. It was firstly created

O. Alharasees (✉) · U. Kale
Department of Aeronautics and Naval Architecture, Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics, Budapest, Hungary
e-mail: oalharasees@edu.bme.hu



T. H. Karakoc et al. (eds.), *New Technologies and Developments in Unmanned Systems*, Sustainable Aviation, https://doi.org/10.1007/978-3-031-37160-8_38

using the Swiss cheese model developed by James Reason (Reason, 1990). This conceptual framework has been applied to accidents and incidents in a variety of fields, including medical science (Diller et al., 2014), naval operations (Celik & Cebi, 2009), petroleum industry (Aas, 2008), construction (Xia et al., 2018), rail transport (Zhan et al., 2017), mining (Lenné et al.,2012), security and safety (Fu et al., 2020), and aviation (Li et al., 2008; Ancel & Shih, 2012).

For 10 years, the Department of Defense (DOD) has successfully employed the human factor analysis and classification system (HFACS) categorization to identify the human error in UAV incidents (Cotter & Yesilbas, 2014). It is critical not to overlook the undeniable human presence in UAVs and the potential human-related cause elements in UAV accidents to decrease and avoid such occurrences effectively. The HFACS framework has four primary categories and 19 subcategories. In this research, the present researchers consider 15 subcategories. The HFACS is beneficial for determining which variables have arisen historically and which ones should be prioritized. The HFACS originated from the "Swiss cheese model" reasons to explain the aviation system failure in this research.

On the other hand, the analytic hierarchy process (AHP) is a well-recognized "multicriteria decision-making (MCDM)" method for quantitative scoring techniques and an exceptional methodology for complex decision-making (Saaty, 2008). This method can help decision-makers classify significances and make the optimum selection (Saaty, 1990). An additional benefit of the AHP is to obtain mutually subjective and objective considerations by arranging complex opinions to a series of pairwise comparisons and then making the decisions.

Several previous researches employed AHP in UAV operations in the literature. Ting et al. used AHP to assess the UAV training system based on visual stimulation (Ting et al., 2018). Li, Xiaoyang, et al. developed a UAV route evaluation algorithm based on CSA-AHP and TOPSIS to solve the problem of UAV route evaluation (Li et al., 2017). Another significant usage in safety and security is creating a decision support model for UAV-aided disaster response using the AHP-TOPSIS method by Yildizbasi and Lütfü (Makalesi et al., 2020).

This research aims to evaluate the elements that influence and affect the UAV operators based on the HFACS and investigate the human factor accident causation from the UAV operators' point of view. The present study examines the preferences of the two operator categories, namely, (i) licensed UAV operators and (ii) non-licensed UAV operators, based on the primary criteria. In order to create a general hierarchical model, the analytic hierarchy process (AHP) is employed in this research. These decision-making models are primarily built on two layers in order to develop evaluator preference loads for (i) the assessment procedure, (ii) preventing complication, and (iii) lacking information from other AHP functions. In this study, the Saaty scale was utilized for scoring to depict lost data utilizing matrices that could be computed using a particular technique.

## 2 Method

Choosing the alternatives and sub-criteria should be determined or selected depending on their attributes, according to the MCDM technique. In MCDM scenarios, a specified number of options are constructed, sorted according to the evaluator's priorities, and scored using the overall hierarchy.

The primary technique employed in the research is the analytic hierarchy process (AHP), a popular multicriteria decision-making (MCDM) technique to investigate the major and main characteristics of human factor accident causation in UAVs.

The present authors created a two-level hierarchy model generated from the HFACS with four main criteria extracted from the "Swiss cheese model" and reflected on the UAVs system, as shown in Fig. 1. The model categorizes the main types of aviation human factor accident causation factors from the HFACS model: (i) organizational influences, (ii) supervision, (iii) preconditions, and (iv) unsafe acts. Fifteen sub-criteria were considered in the research which suit the UAV system in this present research.

Figure 2 demonstrates the hierarchical model for the HFACS for UAVs with the components of each level.

Because the AHP utilizes the unique properties of pairwise comparison matrices (PCM), the choice of decision-makers between specific pairs of options illustrates the importance and priority of a particular aspect over another based on a scale (see Table 1). The matrix of pairwise comparisons (see Eq. 1) $A = [a_{ij}]$ represents the strength of the decision-makers' preference between individual pairs of alternatives ($A_i$ versus $A_j$, for all $i, j = 1, 2, \ldots, n$). The pairwise comparison matrix can be given as follows (Eq. 1):

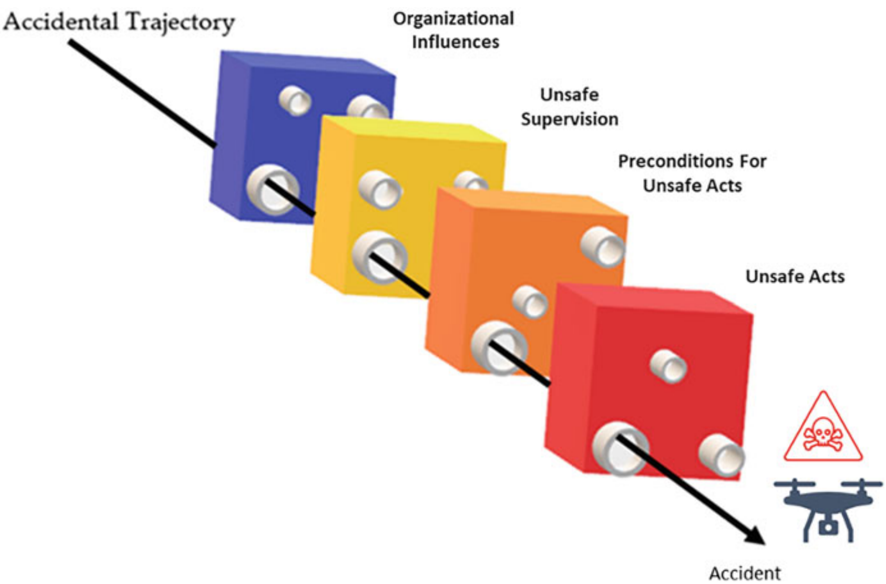


**Fig. 1** Swiss cheese model based on HFACS for AUV

**Fig. 2** The HFACS-AHP hierarchal model

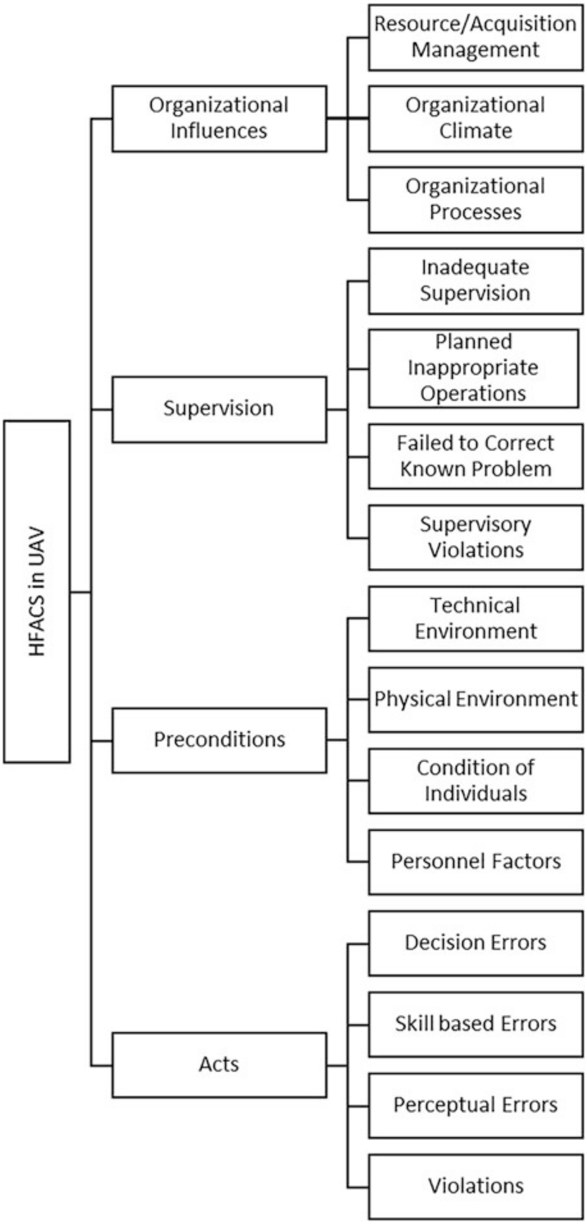

**Table 1** Saaty fundamental scale

| Numerical values | Verbal scale | Explanation |
|---|---|---|
| 1 | Equal importance of both elements | Two elements contribute equally |
| 3 | Moderate importance of one element over another | Experience and judgment favor one element over another |
| 5 | Strong importance of one element over another | An element is strongly favored |
| 7 | Very strong importance of one element over another | An element is very strongly dominant |
| 9 | Extreme importance of one element over another | An element is favored by at least an order of magnitude |
| 2,4,6,8 | Intermediate values | Used to compromise between two judgments |

$$A = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2j} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1j}} & \frac{1}{a_{2j}} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & \frac{1}{a_{in}} & \dots & 1 \end{bmatrix} \tag{1}$$

The geometric mean of each group is calculated in the pairwise comparison matrices for prioritization proposes and to show the influence of each aspect in the model on each level. Because most experience matrices are unreliable, the matrix consistency ratio CR should be smaller than 0.1 for groups.

## *2.1 Questionnaire*

An online AHP-based survey was designed and performed among UAV operators in this research. Sixteen UAV operators (average age 25 years) participated in a two-level hierarchal model grouped into two categories of UAV operators, namely, (i) licensed UAV operators (44%) and (ii) non-licensed UAV operators (56%) from 12 different countries as shown in Fig. 3 (right). Since the requirement to operate UAVs is different based on the field or the operation sector, it is essential to investigate the type of operation the participated operators are working on (Fig. 3, left).

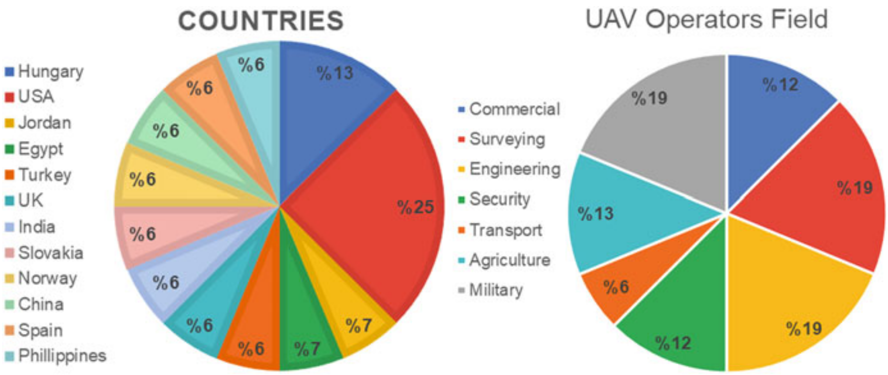


**Fig. 3** Countries of the participants (right) and work sector of the participants (left)

**Table 2** Licensed UAV operators PCM for the first level

| Licensed UAV operators – first level | | | | | |
|---|---|---|---|---|---|
| HFACS | Organizational influences | Supervision | Preconditions | Acts | Weights (%) |
| Organizational influences | 1.00 | 1.81 | 2.80 | 0.62 | 28.10 |
| Supervision | 0.55 | 1.00 | 0.71 | 0.36 | 13.29 |
| Preconditions | 0.36 | 1.40 | 1.00 | 0.20 | 12.23 |
| Acts | 1.62 | 2.75 | 5.03 | 1.00 | 46.37 |
| CR = 0.0347 | Sum= | | | | 100 |

## 3 Results and Discussions

The AHP method shows the variances between the groups' overviews after evaluating and displaying the participants' preferences in the model. Based on pairwise comparisons, the AHP approach will highlight the crucial features. The geometric mean has been used to gather and analyze the responses.

The following tables (Tables 2 and 3) show the aspects (weights, final score, and consistency ratio) that have been computed for the first level in the HFACS model characteristics from each group based on the collected responses of the two groups of UAV operators and by employing the AHP, evaluating and weighing the characteristics in each level individually.

The viewpoints of the two groups would reveal the differences between groups, which may increase related to expertise degree and work category. Comparing different groups of participants would make it easier to evaluate and weigh various individual aspects of UAV accident causation factors from other overviews. As shown in both groups' overviews, unsafe acts would be the primary motive to cause the accidents, so investigating the subcategories of unsafe acts would give a more precise evaluation for the source of UAV mishaps.

**Table 3** Non-licensed UAV operators PCM for the first level

| Non-licensed UAV operators – first level | | | | | |
|---|---|---|---|---|---|
| HFACS | Organizational influences | Supervision | Preconditions | Acts | Weights (%) |
| Organizational influences | 1.00 | 2.17 | 2.42 | 0.88 | 31.66 |
| Supervision | 0.46 | 1.00 | 2.72 | 0.28 | 18.10 |
| Preconditions | 0.41 | 0.37 | 1.00 | 0.52 | 12.18 |
| Acts | 1.14 | 3.51 | 1.94 | 1.00 | 38.06 |
| CR = 0.08535 | Sum= | | | | 100 |

**Table 4** Licensed UAV operators PCM for the second level

| Licensed UAV operators – second level | | | | | |
|---|---|---|---|---|---|
| Unsafe acts | Decision errors | Skill-based errors | Perceptual errors | Violations | Weights (%) |
| Decision errors | 1.00 | 0.74 | 5.29 | 3.89 | 37.7 |
| Skill-based errors | 1.35 | 1.00 | 5.01 | 4.23 | 43.4 |
| Perceptual errors | 0.19 | 0.20 | 1.00 | 2.80 | 11.4 |
| Violations | 0.26 | 0.24 | 0.36 | 1.00 | 7.5 |
| CR = 0.0804 | Sum= | | | | 100 |

**Table 5** Licensed UAV operators PCM for the second level

| Non-licensed UAV operators – second level | | | | | |
|---|---|---|---|---|---|
| Unsafe acts | Decision errors | Skill-based errors | Perceptual errors | Violations | Weights (%) |
| Decision errors | 1.00 | 0.72 | 1.83 | 4.82 | 33.0 |
| Skill-based errors | 1.39 | 1.00 | 1.88 | 3.51 | 36.8 |
| Perceptual errors | 0.55 | 0.53 | 1.00 | 4.88 | 23.1 |
| Violations | 0.21 | 0.28 | 0.21 | 1.00 | 7.1 |
| CR = 0.0422 | Sum= | | | | 100 |

The unsafe acts sub-criteria (weights, final score, and consistency ratio) that have been computed for the second level in the HFACS model characteristics from each group are shown in Tables 4 and 5 numerically and in Fig. 4 graphically.

Looking into the second level of the model (Fig. 4) for the sub-criteria of unsafe acts also provides a clear overview of the specific issue from the operators' eyes. These are the decision errors that are directly linked to the inadequate training of UAV operators. In fact, combining both groups to compare the differences, as shown

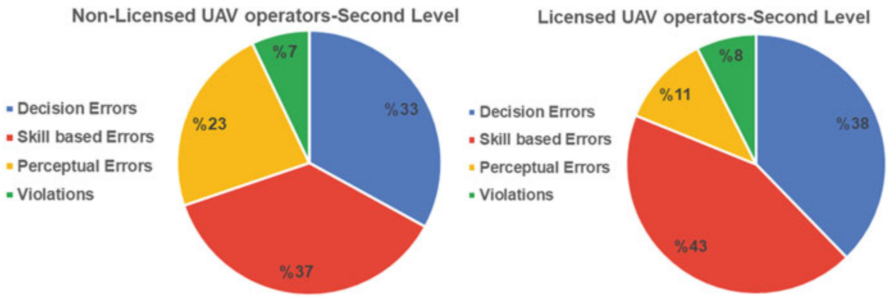


**Fig. 4** Second level (unsafe acts) non-licensed (right) and licensed (left)

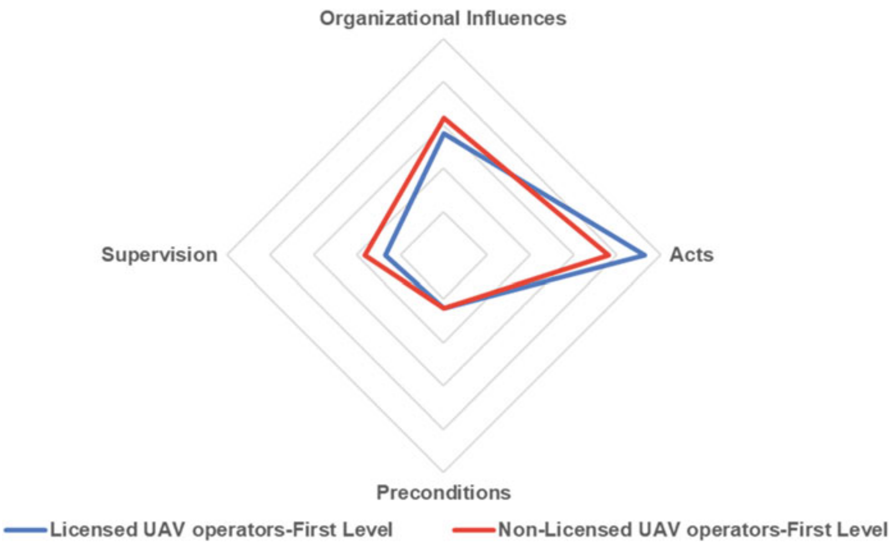


**Fig. 5** HFACS model both groups comparison

in Fig. 5 in the first level, illustrates the importance of focusing on the training techniques. The authorization to use UAVs also going in the second level of the model would highlight the significance of framing bullet points in UAV operators' training. As shown in Fig. 6, the decision- and skill-based errors are the crucial factors in accident causation from the participant's point of view.

The comparison shows that the discrepancies become clear at every level when considering more groups and multiple levels.

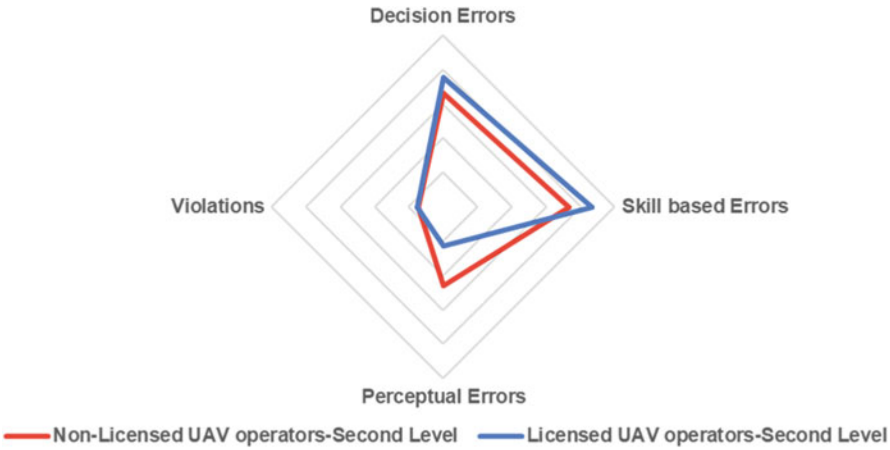


**Fig. 6** Second level unsafe acts both groups comparison

## 4 Conclusion

The findings revealed a preference order and scaling for HFACS accident causation in UAV operations based on the participating operators' responses to the AHP procedure, which shows the critical factors within each level and gives a reliable indicator of the important aspects. In order to assess essential features in a futuristic UAV environment and control critical human errors, multicriteria methods, especially AHP, played a crucial role. The discrepancies between the views are demonstrated using quantitative and qualitative criteria and the conventional, basic, and simple analytical hierarchical process (AHP) decision-making approach.

The results of this survey were based on a total of 16 UAV participated operators from two groups based on the minimum requirement of UAV license and different work sectors. The outcomes of this research highlighted the importance of operators' skills and decisions in the system.

This research shows that the UAV operators' unsafe act plays a dominant role in the HFACS model for all participants. The organizational influences follow this in the first level which could be dealt with in detail if there were a common image of the UAV operator's license requirement. The second level of the model reflected the lack of training for UAV operators.

**Acknowledgment** The present researchers would like to thank the support given to this publication from KTI (Közlekedéstudományi Intézet Nonprofit Kft.) – BME (Budapest University of Technology and Economics) Project, proposal titled "Assessing Operators (Pilot, Air Traffic Controller) Total Loads and Evaluating Aeronautical Decision-Making."

## References


Aas, A. L. (2008). The Human Factors Assessment and Classification System (HFACS) for the oil & gas industry. In *IPTC International Petroleum Technology Conference*. OnePetro. https://doi.org/10.2523/IPTC-12694-MS

Ancel, E., & Shih, A. T. (2012). The analysis of the contribution of human factors to the in-flight loss of control accidents. In *12th AIAA Aviation Technology, Integration and Operations (ATIO) conference and 14th AIAA/ISSMO multidisciplinary analysis and optimization conference*. https://doi.org/10.2514/6.2012-5548

Celik, M., & Cebi, S. (2009). Analytical HFACS for investigating human errors in shipping accidents. *Accident Analysis & Prevention, 41*(1), 66–75. https://doi.org/10.1016/J.AAP.2008.09.004. Pergamon.

Cotter, T., & Yesilbas, V. (2014). Structural analysis of HFACS in unmanned and manned air vehicles. In *Proceedings of the American society for engineering management 2014 international annual conference*. American Society for Engineering Management (ASEM).

Diller, T. W., et al. (2014). The Human Factors Analysis Classification System (HFACS) applied to health care. *American Journal of Medical Quality, 29*(3), 181–190. https://doi.org/10.1177/1062860613491623. SAGE.

Fu, L., et al. (2020). Investigation into the role of human and organizational factors in security work against terrorism at large-scale events. *Safety Science, 128*, 104764. https://doi.org/10.1016/J.SSCI.2020.104764. Elsevier.

Lenné, M. G., et al. (2012). A systems approach to accident causation in mining: An application of the HFACS method. *Accident Analysis & Prevention, 48*, 111–117. https://doi.org/10.1016/J.AAP.2011.05.026. Pergamon.

Li, W. C., Harris, D., & Yu, C. S. (2008). Routes to failure: Analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system. *Accident Analysis & Prevention, 40*(2), 426–434. https://doi.org/10.1016/J.AAP.2007.07.011. Pergamon.

Li, X., et al. (2017). UAV route evaluation algorithm based on CSA-AHP and TOPSIS. In *2017 IEEE International Conference on Information and Automation, ICIA 2017* (pp. 915–920). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICINFA.2017.8079033

Makalesi, A., Yıldızbaşı, A., & Gür, L. (2020). A decision support model for unmanned aerial vehicles assisted disaster response using AHP-TOPSIS method. *European Journal of Science and Technology (Avrupa Bilim ve Teknoloji Dergisi), 20*, 56–66. https://doi.org/10.31590/EJOSAT.737764

Reason, J. (1990). Human error. *International Journal of Man-Machine Studies, 39*, 1051–1057. Cambridge University Press.

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1). https://doi.org/10.1016/0377-2217(90)90057-I

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences, 1*(1), 83–98. https://doi.org/10.1504/IJSSci.2008.01759

Ting, W. T., et al. (2018). Research on UAV simulation training system based on visual simulation. In *Proceedings of 2018 IEEE International Conference on Mechatronics and Automation, ICMA 2018* (pp. 1972–1977). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICMA.2018.8484640

Xia, N., et al. (2018). A hybrid BN-HFACS model for predicting safety performance in construction projects. *Safety Science, 101*, 332–343. https://doi.org/10.1016/J.SSCI.2017.09.025. Elsevier.

Zhan, Q., Zheng, W., & Zhao, B. (2017). A hybrid human and organizational analysis method for railway accidents based on HFACS-Railway Accidents (HFACS-RAs). *Safety Science, 91*, 232–250. https://doi.org/10.1016/J.SSCI.2016.08.017. Elsevier.